Valuing uncertainty part I: the impact of uncertainty in GHG accounting

By: Gregg Marland

Abstract: Background: It has become increasingly evident in the literature that a correlation needs to be made between uncertainty in GHG emissions estimates and the value of emissions. That is, emissions with larger uncertainty are less desirable than those with smaller uncertainty. In fact, concrete advances in trade and reduction agreements depend on finding a set of methodologies for dealing with uncertainty that is acceptable to all parties. Results: Here, we assume that a cost, or value, can be assigned to changes in GHG emissions. As this cost can be assigned to emissions (or sequestrations), then so must a cost be assigned to the associated uncertainty. Standard methods from the actuarial sciences provide an approach to this valuation and we apply these same ideas to dealing to GHG accounting. Conclusion: This framework will allow us to address issues related to agreement structures and motivations for reducing uncertainty, and will enable objective comparisons between options.

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Valuing uncertainty part I: the impact of uncertainty in GHG accounting

Eric Marland*[1], Jenna Cantrell[1], Kimberly Kiser[1], Gregg Marland[2] & Kevin Shirley[1]

Background: It has become increasingly evident in the literature that a correlation needs to be made between uncertainty in GHG emissions estimates and the value of emissions. That is, emissions with larger uncertainty are less desirable than those with smaller uncertainty. In fact, concrete advances in trade and reduction agreements depend on finding a set of methodologies for dealing with uncertainty that is acceptable to all parties. **Results:** Here, we assume that a cost, or value, can be assigned to changes in GHG emissions. As this cost can be assigned to emissions (or sequestrations), then so must a cost be assigned to the associated uncertainty. Standard methods from the actuarial sciences provide an approach to this valuation and we apply these same ideas to dealing to GHG accounting. **Conclusion:** This framework will allow us to address issues related to agreement structures and motivations for reducing uncertainty, and will enable objective comparisons between options.

Uncertainty

With an evolving political environment of negotiated commitments, legal restrictions or other measures to limit emissions of GHGs, and of markets to trade in emissions permits, there is a growing need to accurately evaluate carbon stocks and flows [1]. Our concerns here are:

- Finding a general **accounting** framework that makes sense and is generally acceptable;
- Properly accounting for how much carbon is released to the atmosphere;
- Correctly valuing carbon released to the atmosphere;
- Understanding the implications of carbon accounting frameworks and potential management strategies (for biofuels, forestry, land-use change, industrial processes, and so on).

In all cases it is important to deal with how much carbon is released to (or sequestered from) the atmosphere as CO_2, when it is released, and the uncertainties in evaluating both the quantity and time of release. When different carbon flows have substantial differences in the **uncertainty** of their measurement or estimation, it is important to deal proactively with this uncertainty. The time of carbon release is of particular concern currently in considerations of land-use change and biofuels where emissions and sequestration occur within the same spatial system but not necessarily contemporaneously; but time is relevant for lifecycle analyses generally where emissions and sequestration cover the interval from production to end-of-life management. When uncertain quantities are distributed over time, the uncertainty gains another key dimension. It makes sense that a party should not receive credit for sequestration unless it is reasonably certain that it has happened and it makes sense that emissions should not be charged until it is reasonably certain that they have happened. Our focus in this article is on dealing with the uncertainty in CO_2 emissions estimates, which is followed by a second article in this issue of *Carbon Management* that shows the effect on accounting for the time value of emissions [2].

Anthropogenic sources of CO_2 emissions

Human activities that can lead to significant quantities of CO_2 emissions include: coal, petroleum, natural gas, biofuel and bioproducts consumption; natural-gas flaring; industrial processes such as cement

Key terms

Accounting: In this context, accounting refers to utilizing an inventory of quantities and attribute those quantities to various parties according to some set of rules. For carbon accounting, this may refer to allocating the costs of adaptation or mitigation to various parties according to their activities in carbon emissions or sequestration.

Uncertainty: Value that defines the accuracy level of a reported value. This can be due to measurement error, lack of available data, modeling assumptions or future estimation.

Anthropogenic: 'Of human source' or 'caused by human activity'. Anthropogenic emissions are human-caused emissions from power plants, automobile emissions, and industrial processes.

manufacture; land-cover and land-use change; and human and domestic-animal respiration. Our ability to measure these **anthropogenic** emissions, their time profiles, and their long-term (and short-term) implications varies widely, and yet we need to deal with them within a consistent framework.

Globally, we now have formal agreements in place, pending, or under discussion that dictate specific reductions in some types of emissions based on current or prior levels. For the time being, no restrictions on CO_2 emissions related to human respiration or to agricultural food products and their trade (e.g., domestic-animal respiration) have been imposed and we do not consider these further in this article. For all of the other categories emissions are measured or estimated in some way, and emissions limits and/or trading of emissions permits among sources or categories is often permitted without general consideration of the uncertainty in measurement or the time of emissions. Some categories of emissions or emissions reductions are excluded from some systems when it is judged that uncertainties are so large as to preclude fungibility [101]. Emissions commitments, carbon taxes, cap-and-trade systems, emissions offsets, carbon footprints, mitigation and adaptation strategies are all now generally discussed, and sometimes implemented, without considering independent monitoring and verification or the uncertainty or timing of emissions estimates [3].

The issues of uncertainty and time are especially acute currently for consideration of carbon flows related to biomass energy and land-use change, because these are areas where measurement of carbon flows is particularly difficult and subject to uncertainty, and because carbon flows occur in both directions (both to and from the atmosphere), and yet these two directions of flow are often not contemporaneous, so that net flows within a typical accounting period (e.g., a year) may not reflect the net flows integrated over longer times such as a forest rotation period ([4–7]). This article is focused on the treatment of uncertainty for carbon flows, particularly when there is a need to compare or trade carbon flows with significantly different levels of uncertainty.

Uncertainty in emissions estimates

The IPCC volumes on methods for national GHG emissions inventories provide extensive and valuable discussions for estimating uncertainty [8], but the challenge is how to deal with this uncertainty in emissions commitments or markets. Several edited volumes have collected a variety of papers that begin to confront this challenge [9,10].

In basic scientific inquiry there is generally a desire to reduce uncertainty, but in climate change and emission inventory estimates there are some very important additional issues that confound that objective. We understand that reducing the level of uncertainty will help create better estimates of emissions, and help guide better science and more accurate decision-making. In the name of science then, we can agree that more accurate data is desirable. With current policies it is not clear, however, that it is to everyone's benefit to reduce uncertainty.

It also is not yet clear what will be done with this knowledge of uncertainty. We argue here that as it is accepted that carbon emissions have some value, or cost, the question of uncertainty takes on another role. Recognizing the value of carbon emissions, perhaps in a quest to mitigate or adapt to the increasing carbon in the atmosphere, brings greater importance to the level of uncertainty in emissions estimates. Uncertainty, and differences in the levels of uncertainty, raise important questions about the cost of emissions, whether or not emissions commitments have been met, and how emissions permits can be purchased or traded.

Uncertain ambiguity

We now have formal agreements in place that require specific reductions in emissions based on current or prior levels. In order to fulfill those obligations, careful measurements or estimates must be made at some reference point and at ongoing periodic points in time to demonstrate that those reductions have truly taken place. We should have some understanding of the confidence conveyed in our estimates. Although the choice of confidence interval can be chosen depending on one's risk tolerance, in this article we have chosen to represent that the uncertainty conveyed captures the correct value with 95% confidence.

To introduce some of the primary issues surrounding uncertainty in agreements to limit emissions, we present three simplified illustrations.

Does carbon sequestration offset carbon emissions?

In the first illustration, we suppose that one party will release 100 tons CO_2-e of emissions and wishes to compensate by trading with a party that will sequester 100 tons CO_2-e **(Figure 1)**. Suppose further, however, that the emissions have a level of uncertainty estimated to be ±5% and the sequestration has an uncertainty of ±10%. Are the emissions and sequestration equivalent? What is the difference in value between the emissions and the sequestration? What is the value of reducing uncertainty relative to the value of the emissions and sequestration?

Have carbon emissions commitments been met?

As a second illustration, suppose that a country had 100 tons CO_2-e of emissions in 1990 and has agreed to reduce those emissions by 10% by the year 2020 (Figure 2). This means that the emissions in 2020 need to be 90 tons CO_2-e or less. This sounds relatively simple, until we include uncertainty. An uncertainty level of 20% at 95% confidence is not out of the realm of possibility (large, but useful for this demonstration).

Instead of emissions of 100 tons CO_2-e of emissions in 1990, the country now has emissions of 100 tons, ±20 tons (with 95% confidence). That gives a range of possible reference emissions that extends between 80 and 120 tons at the 95% confidence level (Figure 2). How much does the country have to reduce their emissions by 2020 and how is it calculated? If we are concerned only at the central tendency, the requirement is still 90 tons, but if we are interested at the 95% confidence level, then a 10% reduction from the 120 (100 ± 20) is 108. So the requirement could be met if the upper bound of the 95% confidence level is reduced from 120 to 108 tons, and this can be demonstrated if emissions can be calculated to be 100 tons CO_2-e of emissions with an uncertainty level of ±8% (100 ± 8). That would mean that the 10% reduction at the 95% confidence level would be met (we are 95% confident that the correct value lies between 92 and 108) by reducing the uncertainty between 1990 and 2020, even though no real change might have occurred. Note that Figure 2 assumes that the 1990 and 2020 values are estimated independently. In fact, it may sometimes be possible to estimate the change in emissions over time (trend uncertainty) independently of the two end values and with less uncertainty than the difference between the two end values.

Consider alternatively for Figure 2, that the country reports 90 tons CO_2-e emissions in 2020 but the uncertainty has increased from ±20% in 1990 to ±40% in 2020. Then, the reported central number has indeed dropped by 10%, but the top of the 95% confidence interval has actually increased by 6 tons (90 ± 36 tons). This means that the true value might have actually increased. In fact, even with the same uncertainty in 2020 (90 tons ±20%), we cannot be sure that the emissions have dropped since the 95% confidence intervals overlap.

How much carbon tax is owed?

Finally, on a different scale, we might look at a third illustration that is relevant to a single power plant that is required to pay a fee in proportion to its emission levels (Figure 3). The plant could report that it released 30 tons of CO_2-e with 5% uncertainty, or it could report 28 tons with 12.5% uncertainty. The second quantity covers the same upper range of emissions values, but with larger uncertainty. What is the result? The plant has good reason to maintain the higher level of uncertainty because it pays for only 28 tons released rather than 30. There are additional possibilities for problematic results if the uncertainty is asymmetric [11].

In all of these cases, uncertainty creates a problem in the calculations. In the first case, we see the need to quantify uncertainty for the purposes of comparison. In the second case, we see that methods are needed to make the use of uncertainty in agreements (at every scale) uniform. In the last case, we see the possibility for a motivation to keep uncertainty levels high.

In this article, we reinforce the notion that we need to develop a consistent methodology for dealing with uncertainty and show an approach that effectively deals with all of the issues outlined above. We do this by borrowing ideas from the insurance industry, revealing how their treatment of uncertainty translates into a reliable but flexible methodology that deals with uncertainty but also motivates reducing uncertainty. We recognize that some consequences of the approach may still be intuitively negative, but we believe that the methods are clear and consistent and provide a basis for useful policy.

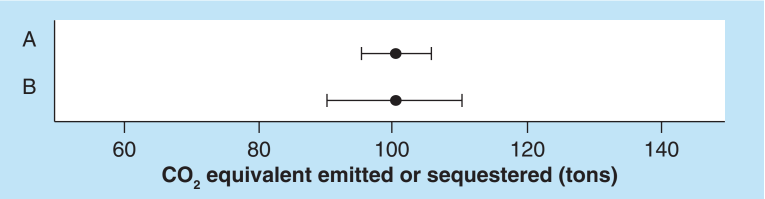

Figure 1. Comparing carbon emissions with carbon sequestration. What is the difference between emissions and/or sequestration of the same magnitude but with different levels of uncertainty? How do we quantify the difference? The central estimates of Figure 1 are shown with error bars that reflect the 95% confidence bounds for two estimates of carbon flows flows (emissions in line A and sequestration in line B).

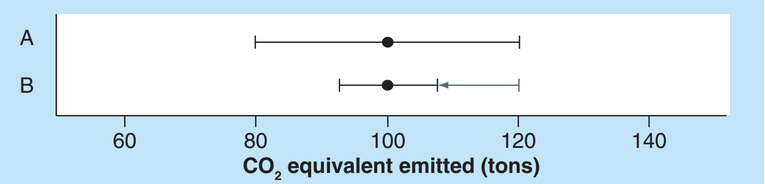

Figure 2. Evaluating carbon emissions commitments. Once we quantify the uncertainty, how do we value reductions in uncertainty compared to reductions in the emissions estimates? Can reducing the uncertainty count as a reduction in emissions if initial estimates of emissions (line A) are later estimated with les uncertainty (line B)?

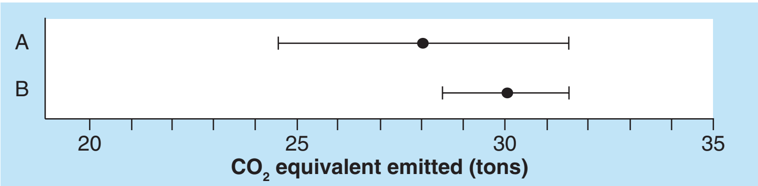

Figure 3. Estimating carbon emissions with uncertainty. If we can quantify the uncertainty as part of the total emissions, are we content with different emissions estimates (lines A and B) having the same overall value at the 95% confidence level even though the central estimates and the uncertainty are not the same?

Once the quantities and uncertainties of emissions are clearly formulated, we can then look at the consequences of emissions that do not occur simultaneously in time [2]. The same ideas that motivate the methods to deal with uncertainty provide a basis for approaching difficulties with time-distributed emissions.

An analogy & the cost of carbon emissions

The cost of carbon

We recognize that the release of CO_2 and other GHGs into the atmosphere contributes to global climate change, which results in some cost to society. In order to mitigate the cost society faces due to the release of CO_2 into the atmosphere, there has been an evolution in the political environment of commitments to limit the emissions of GHGs and the emergence of markets to trade in emissions permits. Carbon emissions may derive a cost as a result of a carbon tax, a cap-and-trade restriction on carbon emissions, an evaluation of the damage function for carbon emissions, an evaluation of the social cost of emissions, or of a legal or negotiated limit on the mass of GHG emissions. Choosing which method to use is a contentious issue and we do not attempt to do that here. Instead, we acknowledge the existence of such a valuation and focus on the implications that succeed its determination. When emissions have a cost (value), there are important implications for uncertainty and for the time-dependent value of emissions.

We note a few truisms about the costs associated with emissions. First, effective and consistent management suggests that treaty signers and governing bodies must administrate any regulations related to the cost of emissions. It falls on these same bodies to organize efforts to distribute or ameliorate the incurred costs. Presumably these bodies also facilitate efforts to adapt and mitigate the real costs of carbon emissions. Ultimately, however, these costs will be passed down to companies and individuals. How this will ultimately happen has yet to be determined.

What this means is that we treat these treaty signers and governing bodies as the entities that collect and invest monies related to carbon emissions, and then use those investments to organize efforts to adapt to and mitigate (including avoiding) the effects of the emissions. This may be as simple as distributing costs to encourage some activities while discouraging others.

Margins & risk charges

We have previously made an analogy between the pricing of life insurance and the pricing of carbon emissions (Figure 2 in [12]). Many of the ideas that arise from the life insurance analogue are discussed by Shirley *et al.*, including present value calculations, contract valuations and ideas on contract negotiation [12]. The theories do not carry over exactly to valuing GHG emissions, but the basic ideas provide a useful guide.

The primary issue we are interested in for this article is uncertainty. Given the analogy outlined above and the results from earlier works, we look at the life insurance industry to see what standard practices are used in dealing with uncertainty. The insurance industry adds into their fees to cover the net present value of expected payouts an additional charge called a margin, or **risk charge**. This risk charge is essentially insurance for the insurer. What happens, for example, if an unforeseen event occurs and more people than predicted die before the expected time? The risk charge takes into account basic variability in the data and also the probability of rare events that might influence their costs. The total price (C) for insurance is then:

$$C = PV + M$$

where PV is the present value of the cost and M is the risk charge or margin.

The risk charge accounts for the difference between the actual payment and the present value or expected cost, reflecting the cost of the variation in estimates going into the present value calculations. In other words, it reflects the downside cost for the risk of future results that differ from what is expected. The risk charge is also referred to in the insurance industry as the loading. Generally, a greater variance leads to a greater risk charge, although other factors, such as the probability that an event will occur in the tail end of the distribution, are also considered.

We propose here that a risk charge be added to the valuation of emissions, based on levels of estimated error and uncertainty in the calculations and measurements, and the probabilities of unexpected events (e.g., forest fires, leakage, and so on). In the case of carbon, we have

Key term

Risk charge: Term derived from the insurance industry describing a fee added to the basic cost of a good or service that incorporates potential costs incurred to the seller as a consequence of the sale. An example is that of selling automobile insurance and adding a charge that reflects the probability of an unexpected number of accidents involving policy holders occurring at the same time.

identified three primary sources of error or uncertainty that will each contribute to the risk charge.

- Economic forecasting, including the value of emissions;
- Estimating quantities of carbon emitted/sequestered;
- Estimating the timing of carbon emissions/ sequestrations.

The first is the error in economic forecasting. The returns on investments are determined based on projections pertaining to the economic growth of the world or country. These predictions are subject to greater variation as time increases. We include in this the price of carbon release. Accurate estimates of this cost are also elusive and difficult to predict farther into the future. After initial transient fluctuations in the price of carbon, it might be assumed to follow basic economic trends. However, even after a market for carbon is well established, scientific discoveries or policy changes may create large, sudden changes in the price of carbon, making long-term predictions problematic.

The second source of error and uncertainty is in calculating or estimating the actual quantities of carbon that are released to the atmosphere. Errors and uncertainty in the land-use change and forestry sector include, for example, estimation of area of forest harvesting, carbon density on the landscape, variations in burning efficiency, the utilization of forest products, and waste volume.

The final source of error is related to the timing of the release of the carbon into the atmosphere. We have assumed that the release of carbon from particular products or activities can be fit to probability distributions; however, we need to know how much error might propagate through the present value calculations. The possible approaches to calculating the risk charge are outlined in the next section.

Calculating margins

Rubin *et al.* outline a framework for analyzing methods used to calculate uncertainty for life insurance and annuity based products [13]. In this article, several standard approaches for quantifying margins for uncertainty are identified and compared. These include factor-based approaches, discount-related methods, judgment-based on experience studies, stress testing/sensitivity testing, 'quantile' and distribution methods, stochastic modeling (i.e., Monte Carlo methods), cost of capital method, and calibration to the capital markets or insurance pricing.

All of these methods are considered standard methods for the calculation of margins (risk charges). A table is included in the article by Rubin *et al.* that assesses the strengths and weaknesses of each method and advocates for the use of each method under different scenarios [13]. We note these methods to help highlight the fact that most of these methods are already present in the IPCC best practice guidelines for determining uncertainty in lifecycle analysis and GHG calculations [14].

IPCC calculation of margins

The IPCC Guidelines for National Greenhouse Gas Inventories have proposed two tiers to estimate uncertainties [8]. Tier one estimates uncertainty by source category with simplifying assumptions and then uses a simple error propagation method to estimate the overall uncertainty. Tier two estimates uncertainty by source category, selects error distribution functions for each and uses Monte Carlo analysis to derive the overall uncertainty.

Tier one estimation of uncertainty

Tier one individually combines emission factors and activity data to estimate uncertainties for each component of an emissions inventory. It then combines all the uncertainties for different components of the inventory into one national uncertainty using an error propagation method so that an overall error margin can be applied. There are several variables that inform the calculation of the uncertainty for Tier one, including numbers based on expert judgment. The factor-based approach, discount-related approach, stress test and sensitivity test approaches, and quantile distribution methods are also used in the calculations for a Tier one approximation [13].

Tier two estimation of uncertainty

Tier two methods use random sampling to estimate carbon emission data at a source category level or for the inventory as a whole. The use of random sampling helps estimate carbon emissions data at source category levels or for the inventory as a whole.

Monte Carlo analysis can also be used in a restricted way within Tier one to combine activity data and emission factor uncertainties that have very wide or non-normal probability distributions or both. This approach can also help deal with source categories within Tier one that are estimated by process models rather than by the classical 'emission factor times activity data' calculation.

The uncertainty risk charge

Once the uncertainty is calculated, using the IPCC approaches, and converted to a percentage of the central estimate, we suggest that this value can be used to calculate a useful risk charge. This risk charge can be combined with the best estimate to provide greater certainty that commitments within the accounted system have been fulfilled; and the extent of attention to risk, or risk aversion, can be scaled to the situation. The risk charge per ton of carbon or carbon equivalent can be determined and added on to the central estimate to complete the valuation of the emissions.

The current IPCC methodology outlines uncertainty calculations based on the 95th percentile of the probability distribution function. Because that calculation is currently standard, we propose to use that value here for calculations of a risk charge; however, we recognize that this value may be considered too high (too conservative) in some applications. Regardless, a higher or lower value for the confidence interval does not change the basic approach proposed here.

To obtain the risk charge, we multiply the percentage of uncertainty, obtained using the Tier one analysis approach, times the price per ton of carbon. The risk charge is thus calculated as:

$$M = U \times C_{ton}$$

where M is the risk charge, U is the percentage of uncertainty at the 95% confidence level and C_{ton} is the price per ton of carbon.

To obtain the total price (C_{total}), meaning we are including the price of carbon released plus the risk charge, we simply add the two together:

$$C_{total} = C_{ton} + M = C_{ton} + U(C_{ton})$$

where U is the percentage uncertainty and C_{ton} is the price/ton of carbon.

As an example, suppose the uncertainty is 20% at the 95% confidence level. Then, if a ton of carbon emitted costs US$50, the total price per ton will be: total price = $50 + ($50)(20%) = $50 + $10 = $60.

▪ Revisiting the illustrations in the introduction

Coming back briefly to the simple illustrations from the section titled 'Uncertainty' (Figures 1–3), we are now equipped to evaluate the comparisons of the different emissions.

In our first illustration we wanted to compare two values of 100 tons CO_2 equivalent with different levels of uncertainty (Figure 1). Here, we allow uncertainty to play to the conservative side of fulfilling commitments. That is, we over-estimate emissions and under-estimate sequestrations. This means that the emissions will have their uncertainty added on, while the sequestrations will have it subtracted. With the margins incorporated, we now see that the emissions have a valuation equivalent to 105 tons (or 5% added value) while the sequestration is 90 tons (or 10% subtracted value). This creates a differential of 15 tons that are not balanced in the trade and that would need to be made up.

We realize that this will create some controversy, since it implies that equivalently calculated emissions and sequestrations with identical uncertainty do not offset each other. However, this is the nature of dealing with uncertainty in a conservative manner (i.e., in treating both emissions and sequestration at the point of 95% certainty). The difference between the two emissions values will be reduced as uncertainty in either value is reduced. Note too that the difference will be reduced if we take a less conservative approach by using a smaller confidence interval, perhaps one SD rather than two.

The second illustration, of maintaining the same level of emissions (100 tons) while reducing the uncertainty, now shows that the reduction of uncertainty from 20 to 8% does indeed meet the criterion for having achieved a 10% overall reduction (Figure 2). At the 95% confidence level, emissions have been reduced from 120 to 108 tons. This too has the potential for creating some controversy. There is recognition that no real reduction might have taken place at all. And yet we have greater certainty that the emissions are less likely to be as large.

Examination of Figure 3, showing a lower base emission value with a much larger level of uncertainty, reveals that the power plant that reports the lower level of emissions with a higher level of uncertainty did not meet the criteria for a reducing their emissions obligation. At the 95% confidence level, the emissions are unchanged.

Each of these simple examples reveals problems with ignoring uncertainty – and challenges with including it. While we place a value on uncertainty and understand the importance of reducing uncertainty, the necessary result is not completely satisfactory. We can view these examples then as consequences of valuing the uncertainty, as caveats for trying to do so and as motivations for trying to reduce uncertainty.

In 1998, it was proposed to the UNFCCC, that the second SD be used in standard accounting of whether or not commitments had been met [15]. Perhaps the use of an intermediate percentile creates a compromise that balances the benefits of addressing uncertainty while minimizing our intuitive sense of the negatives. It would also be possible to use some fraction of the 95th percentile number as a compromise. We continue to base our illustrations on the 95th percentile, relying on the value of the basic methodology over the specific thresholds that must be negotiated later.

Discussions

As we approach the time when there is a recognized value to carbon emissions (and sequestrations), we are forced to confront the issue of uncertainty. There may be multiple ways of dealing with uncertainty, but uncertainty must be dealt with in a consistent and transparent way across all emissions, from all sources, particularly when uncertainty varies widely among emissions and sources.

In this article we have proposed one such approach, one that borrows some basic foundational ideas from the long and vetted history of the insurance industry. We propose the addition of a risk charge based on standard calculations currently used in the IPCC reporting guidelines. Making an analogy to the life insurance industry does not hold up to intense scrutiny of every detail, but the theoretical foundations are sound and the types of questions that need to be answered provide a guide for a parallel development.

With the addition of a risk charge to the cost of CO_2 emissions and an understanding of the sources of uncertainty in emissions estimates, we can make attempts to reduce uncertainty and to otherwise minimize the effects of uncertainty in both our calculations and in our contractual agreements. Uncertainty can be reduced by improved measurements and improved systems understanding, but emphasis here is on managing uncertainty through development of an appropriate accounting framework. We can motivate decreases in uncertainty through proper valuation of uncertainty and a clear understanding of the implications of uncertainty.

Future perspective

We feel that uncertainty is a huge issue that has evolved into a topic that everyone knows is important but no one knows what to do with it. We feel that this article starts to develop ideas of how to quantify uncertainty in a usable way. We hope that this contribution will initiate the needed conversation that will drive the development of foundational theory to deal with uncertainty and time issues in accounting in climate policies. While not complete as a finished methodology, we see the possibility for the basic approach to be adopted in all climate agreements in the coming years.

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Uncertainty

- An introduction to the concept of uncertainty in the context of climate change and emissions accounting is provided. An understanding of the importance of accurate inventories and accounting methods is discussed.
- Anthropogenic sources: a summary of human caused sources of emissions and the inherent difficulty in quantifying them is provided.
- Uncertainty in emissions estimates: everyone is starting to include uncertainty calculations, but this section raises the issues of what to do once uncertainties are calculated. Why bother if nothing happens?
- Uncertain ambiguity: a set of simple examples that outline the difficulties with quantifying uncertainty or with not making use of uncertainty. This set of examples is by no means exhaustive, only illustrative. We could have used examples derived from many sources, but we chose ones that we felt were easy to understand.

An analogy

- The insurance industry deals with uncertainty all of the time. Maybe we can learn something from how they deal with it.
- Cost of carbon: outlining the ideas that carbon emissions have a cost, even if we cannot yet agree on what that cost might be.
- Margins and risk charges: introduction of the idea of a risk charge, or margin.
- Calculating margins: an overview of how uncertainty might be calculated without going into much detail. Includes basic approaches used in the insurance industry.
- IPCC calculations: a comparison of the approaches outlined in the insurance industry and those already in place in the IPCC methodologies.

Uncertainty risk charge

- Now that we the relevance, here is one idea of how to implement a basic risk charge. We understand that there are other approaches but the article is meant to serve as a starting point and fuel discussion.
- Revisiting examples: given our proposed approach to risk charges, this section revisits the simple examples earlier in the paper and explains the implications in each case.

Discussion

- Discusses the implications and ideas moving forward on this idea of a risk charge. This section also sets up a companion article that outlines in greater detail how the calculations really work. The companion article contains all of the detailed calculations – it is very detailed, which adds value to the current article, as it provides the basic ideas in a basic intuitive story.

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▪ **Introduces the theories of insurance to the carbon accounting field. The paper outlines the basic mathematics for using probability densities in calculating present values for future emissions.**

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▪ **A very general outline created by an insurance giant that discusses all of the ways that margins might be calculated based on what information is available. This paper suggests that the time tested methods of actuarial science uses the very same approaches outlined in the IPCC methodologies.**

14 IPCC. *Good Practice Guidance and Uncertainty Management in National Greenhouse Inventories.* IPCC, Geneva, Switzerland (2000).

15 Government of Canada. *Methodological Issues Inventories and Uncertainties, Paper Number 1 in United Nations Framework Convention on Climate Change, Subsidiary Body for Scientific and Technological Advice, Approaches to Resolving Methodologic Issues Related to National Communications From Annex I Parties, FCCC/SBSTA/1998/MISC.6/Add.1.* Government of Canada, Ottawa, Canada (1998).

▪ Website

101 European Commission. LULUCF in the EU. http://ec.europa.eu/clima/policies/forests/lulucf/index_en.htm